ORIGIN, DISTRIBUTION AND CHRONOSTRATIGRAPHY OF ASYMMETRIC SECONDARY CRATERS AND EJECTA COMPLEXES IN THE CRISIUM BASIN. W. A. Ambrose[1], [1]Bureau of Economic Geology, The University of Texas at Austin, University Station, Box X, Austin, TX 78713-8924, william.ambrose@beg.utexas.edu.

Introduction: The Crisium Basin is an asymmetric, multiring basin of Nectarian age [1]. It is ~740 km in diameter, measured from the outer ring (Fig. 1). There is evidence for a 1,000-km-diameter outer ring, although it is discontinuous [2]. The rings are poorly preserved on the east, west, and southwest margins. The basin contains several radially distributed, asymmetric secondary craters, as well as genetically associated scours and crater chains. These asymmetric secondary craters have polygonal outlines and narrow rims, range in diameter from 10 to 30 km, and are shallow floored (commonly <1.5 km deep). Many are teardrop shaped, reflecting low-angle impacts. Similar morphologies for low-angle impacts have been demonstrated experimentally [3, 4]. The trajectory and source area of these types of secondary craters can be inferred from the orientation of their teardrop-shaped rims, which point away from impact sites. Asymmetric secondary craters in the Crisium Basin are part of a morphological continuum of ejecta features including teardrop-shaped craters, elongate craters, crater chains, and shallow-floored valleys, all present on the southeast margin of the basin (Fig. 2). Crisium ejecta features are best developed on the southeast and northeast margins [5], although some are present to the north and northwest (Fig. 1). This distribution of ejecta reflects an oblique impact from the west, resulting in a downrange butterfly-wing ejecta pattern consistent with ejecta patterns observed in experimental studies of oblique impacts, remote sensing, and modeling [3, 6, 7].

Recognition Criteria: Asymmetric secondary craters in the Crisium Basin are differentiated from morphologically similar, primary craters by shallow floors; lack of slumps that produce asymmetry in small, complex, main-sequence craters; moderate to high levels of degradation owing to Nectarian age; long axis orientation radially from the basin center; and association with scours and crater chains.

Asymmetric outline and shallow floors. Ballistic ejecta from lunar basins are inferred to have been expelled in a wide range of angles, with many at 45° ± 10° [8]. Oblique primary impacts also change the distribution of ejecta angles and increase the potential for low-angle impacts by secondaries [9, 10]. Numerous examples of secondary craters with asymmetric outlines and shallow floors occur in the Crisium Basin with the majority distributed on the southeast margin (Fig. 2).

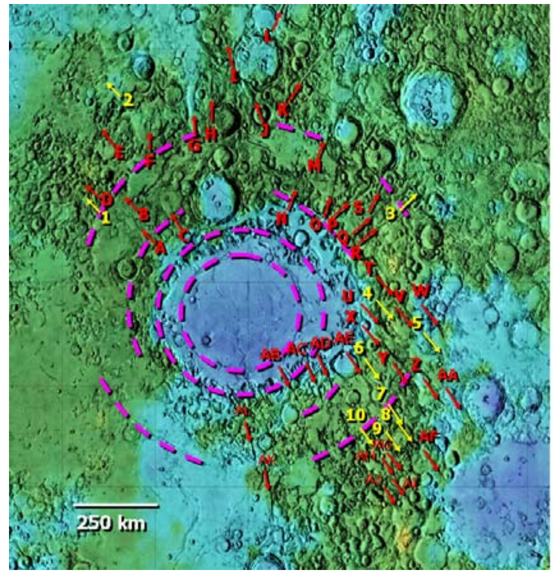

Figure 1. Lidar map of the Crisium Basin, with asymmetric secondary craters indicated by yellow arrows aligned along major axes of craters and pointing toward beaked rim. Scours and crater chains are shown by red arrows. Major basin rings, inferred from scarps and concentric, topographically positive features, are shown as dashed purple lines. Details of the southeast margin are shown in Fig. 2. Data source [11].

Rim structure and Degradation. Minor asymmetry in small, complex, main-sequence lunar craters of primary origin, ascribed to postimpact rim subsidence, is documented for many examples [12, 13]. In contrast, asymmetric secondaries are differentiated from small, complex primary craters by narrow rims and a lack of significant slumps [14, 15, 16]. Moreover, secondary craters exhibit similar levels of degradation with genetically associated impact basins. Crisium secondary craters, crater chains, and scour features exhibit high cratering density values (typically $\geq$0.005 km^{-2}) by craters with diameters $\geq$0.5 km.

Chronostratigraphy: Asymmetric secondaries associated with lunar basins are unique morphological features that can be used to constrain estimated ages of overlapped, extrabasinal landforms such as other craters, scarps, and ejecta from other basins. For example, scour feature F (Fig. 1) overlaps crater Geminus E. Based on this stratigraphic relationship and its greatly degraded nature, Geminus E is interpreted to be Pre-

Nectarian in age. Another example is the crater chain that includes Cartan (formerly Apollonius D; labeled AL in Fig. 2 and also shown in Fig. 3), previously interpreted to be Lower Imbrian in age [17]. Based on its morphology, orientation, and association with other ejecta features, Cartan is interpreted in this study to be Nectarian owing to its origin as Crisium ejecta.

Comparison with other Nectarian Basins: The number and degree of preservation of asymmetric secondary craters and scour features in the Crisium Basin is comparable to that of the Nectaris Basin [14, 15, 16]. Moreover, the Nectaris Basin has an asymmetric distribution of secondary craters and scour features [15], which could suggest it also formed from an oblique impact. However, this asymmetry is likely a result of obliteration of secondary craters and other ejecta features north and northeast of the Nectaris Basin by southern Tranquillitatis and southwestern Fecunditatis lavas, respectively [18]. Rheita E, composed of three overlapping craters northeast of Rheita, has been cited as evidence of a Crisium secondary superimposed on the Nectaris Basin [5]. This is problematic, given the anomalously great distance of Rheita E from the Crisium Basin, its alignment with the Fecunditatis Basin, and its rim sharpness implying a younger origin. Asymmetry in the distribution of ejecta in the Humorum Basin is also attributed to postimpact lava flooding rather than the result of an oblique impact [19]. The low density of well-preserved asymmetric secondary craters in the Humorum Basin relative to those of the Crisium and Nectaris Basins suggests that the Humorum impact event is older than either the Crisium or Nectaris impact events. However, this must be confirmed by acquiring radiometric age data from ejecta fields in these basins to establish a robust relationship between impact basin age and density of well-preserved ejecta features.

Acknowledgment: Publication authorized by the Director, Bureau of Economic Geology.

References: [1] Wilhelms D. E. (1987) *USGS Prof. Paper 1348*, 302 p. [2] Spudis P. D. et al. (1997) *LPS XXVIII*, Abstract #1296. [3] Gault D. E. and Wedkind J. A. (1978) *LPS VIII,* 3843–3875. [4] Forsberg N. K. et al. (1998) *LPS XXIX,* Abstract #1691. [5] Wilhelms D. E. (1976) *Proc. Lunar Sci. Conf. VII*, 2883-2901. [6] Anderson, J. L. B. et al. (2004) *MAPS 39,* 303–320. [7] Artemieva N.A. and Ivanov B. (2004) *Icarus 171*, 84-101. [8] Oberbeck V. R. et al. (1975) *The Moon, 13*, 9–26. [9] Anderson J. L. D. et al. (2003) *J. Geophys. Res., 108(E8),* 13-1 to 13-10. [10] McEwen A. S. and Bierhaus E. B. (2006) *Ann. Rev. Earth. Planet. Sci., 34,* 535–567. [11] USGS (2009) http://pdsmaps.wr.usgs.gov/PDS/public/explorer/html/lidrlvls.htm [12] Melosh H. J. and Ivanov B. A. (1999) *Ann. Rev. Earth Planet. Sci. 27*, 385–415. [13] Melosh H. J. (1980) *Ann. Rev. Earth Planet. Sci. 8*, 65–91. [14] Ambrose W. A. (2008) *LPS XXXIX*, Abstract #1019. [15] Ambrose W. A. (2009) *LPS XL*, Abstract #1015. [16] Clark M. (2006) *The Lunar Observer, June*, 4–10. [17] Olson A. B. and Wilhelms D. E. (1974) *Geol. Map Mare Undarum Quad.*, http://www.lpi.usra.edu/resources/mapcatalog/usgs/I837/. [18] Wood C. A. (2003) *The Modern Moon*, 209p. [19] Ambrose W. A. (2008) *Geol. Soc. Am.,* Abstract 324-8, http://a-c-s.confex.com/crops/2008am/webprogram/Paper48753.html.

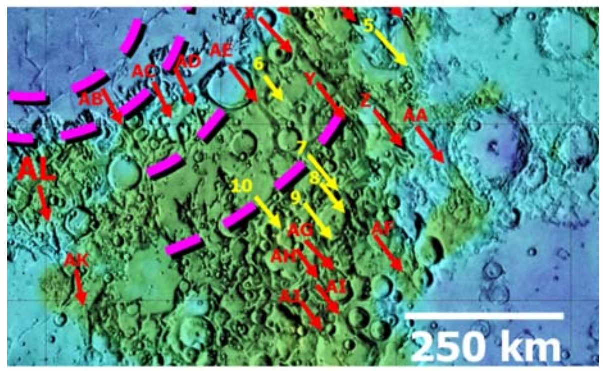

Figure 2. Lidar map of the southeast margin of the Crisium Basin, with ejecta scour features (red arrows) and asymmetric secondary craters (yellow arrows). Cartan (labeled AL) is shown in Fig. 3. Data source [11].

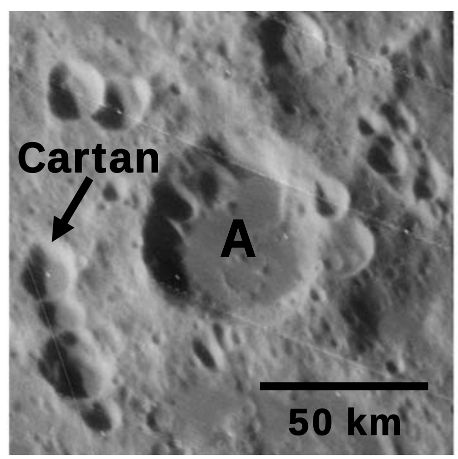

Figure 3. Crater chain west of Apollonius (A), interpreted in this study as Crisium ejecta. Cartan, the northernmost crater, is “AL” in Fig. 2. Modified from Lunar Orbiter 4 Photograph LO-IV-184H.